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Analysis of energy use and CO_2 emission in service industries: Evidence from Sweden

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ABSTRACT

This study analyses the trends in energy use and CO_2 emissions for 19 sub-sectors in the Swedish service sectors following the classification of the International Standard Industrial Classification of all Economic Activities (ISIC) at the 2-digit level of aggregation over the period 1993–2008. This empirical study intends to examine energy use, energy efficiency and CO_2 emissions using data envelopment analysis (DEA) and panel data techniques. DEA is applied to assess energy efficiency within a production framework. Panel data techniques are used to determine which variables influence energy efficiency. The results show that Swedish services industries have increased energy consumption and CO_2 emissions in the period 1993–2008. The results from the DEA show significant variation in energy efficiency across service industries. The results also indicate that this sector has increased technical efficiency and energy efficiency while decreasing CO_2 emissions, especially in the later years of our sample period. The results of panel data techniques show that higher energy taxes, electricity consumption, investments and labour productivity generate higher energy efficiency, while higher fossil fuel consumption leads to lower energy efficiency. All findings of this study are important for developing effective energy policies that encourage better energy use and energy management in the service industries.

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1. Introduction

Recently, the service industries have emerged as a key source of employment and economic growth. It has also proven important in the expansion of international commercial trade and foreign direct investment that strengthen export and import alternatives. This expansion has generated increases in economic growth, greater efficiency in the use of resources, innovation and more possibilities to increase welfare of population. Moreover, this sector has become one of the factors used to measure an economy's progress, its development, its quality and its perspectives [13,36,62].

The service sector represents 63.2% of GDP and 41.9% of labour forces worldwide, whereas sectoral global energy consumption and CO_2 emissions are 9% and 12%, respectively [32,8]. However, as the economy has trended away from industry to services, especially in developed countries, there has been a 69% increase in energy consumption in this sector between 1974 and 2009. More than half of the consumption comes from electricity, which has shown the fastest growth in the last 35 years, rising from 15% to 23% [31,32],[8].

Despite these trends, the service sector has been neglected in energy analysis and the application of energy policies and programmes. Some reasons for this neglect may be the heterogeneity of this segment of the economy, the complexity of the necessary statistical valuation that varies among countries limited detailed and disaggregate information and the sector's lack of energy intensity relative to manufacturing. For instance, in the European Union, the service sector needs around of 1/8 of the energy required by the manufacturing industries to generate one unit of gross production [58,31].

Studies on energy patterns in the service sector have focused mainly on three broad topics. First, many provide a description of energy use applying different approaches. For example, Schipper et al. [52] analysed energy consumption in the service industries of OECD countries and demonstrated that the differences in energy consumption in this sector among countries were mainly due to differing energy sources, building types and vintage. Further, they found that electricity was the energy source with the largest increase. Gowdy and Miller [22] described energy use in the U.S. service sector with an input–output analysis identifying increases in electricity consumption. Mairet and Decellas [41] studied the trends in the energy consumption of the French service sector using decomposition analysis; they suggested that the increase in energy consumption has been led mainly by the economic growth in this sector. Schloman et al. [55] examined and evaluated energy consumption in the German service industries through primary data finding different practices and features in every service sector.

A second area is the direct analysis of energy sources, especially electricity. Krackeler et al. [37] analysed the role of electricity in the generation of CO_2 emissions in OECD service sectors applying a Laspeyres index. The findings indicated that both carbon dioxide emissions from the service sector and electricity also increased as a proportion of final energy use. Collard et al. [11] analysed the effect of the use of information and communication technologies on electricity intensity in the French service sector using a factor demand model. They found that electricity intensity increased because of the use of computers and software.

A final broad topic addresses the barriers to adopting energy efficiency in the service industries. Schleich and Gruber [54] and Schleich [53], in the German context, determined that the limited information about energy use patterns and energy efficiency measures are the most important barriers to improving energy efficiency in service industries.

Given this background and accounting for the fact that energy consumption grew most quickly in the service sector by a rapid expansion of this activity in the economy, further investigation of energy trends in service industries is needed, particularly as these trends imply an increase in the stock of buildings, a growth in the information and technology economies and an increase in labour used by this sector. This research should aim to determine opportunities and design adequate and effective energy policy to strengthen and motivate higher energy efficiency and lower CO_2 emissions in this sector. The objective of this study is to contribute to the analysis of energy use in service industries using different econometric approaches. It will also define the main variables that determine these trends using the Swedish service sector for the period 1993–2008 as a case study.

In this study, energy efficiency is analysed with traditional indicators such as energy intensity and carbon dioxide emission intensity. Here, we will use data envelopment analysis (DEA) to assess energy efficiency within a production theory framework in which energy is one of the many inputs used to produce desirable or undesirable outputs [43,69]. This methodology has been applied in several energy studies with different approaches. For instance, Hu and Kao [28] analysed the energy-saving target for economies of the Asia-Pacific Economic Cooperation. Pardo [70] studied energy efficiency in German and Colombian non-energy-intensive sectors. Ramanathan [49], Zhou and Ang [69] and Oggioni et al. [46] have applied DEA to analyse energy as an input generating both desirable outputs (goods) and undesirable outputs (CO_2 emissions). Azadeh et al. [1] and Pardo [47] used DEA to assess and analyse energy efficiency in energy-intensive sectors. Finally, Boyd and Pang [5] studied the linkage between energy efficiency and productivity.

In Sweden, DEA has been applied to determine productivity growth in retail electricity distribution [26], analyse productivity development in hospitals [18], measure technical efficiency in urban bus systems [51], study economic efficiency in dairy farms [34] and model and compute productivity in public schools [19].

The main contribution of this study is the application of DEA to analyse energy efficiency performance in service industries, which have been little-studied in research on energy use. The results and trends in energy efficiency are then explained through second-stage regressions in terms of several key characteristics, using panel data analysis where studies are limited in the context of DEA and energy.

The following section reviews the economic and energy-use attributes of the Swedish service industries. Section 3 describes the methodology and the data used in this analysis. Section 4 presents and discusses the results. The conclusions are summarised in Section 5.

2. Service industries: Trends and perspectives in Sweden

The service sector has become more important for economic development and growth, as the service share of the economy has increased rapidly. In Sweden, the trends of the industrial sector demonstrate a transformation from traditional manufacturing industries to a knowledge-based service industry. This new industrial composition is characterised by products and services with a greater knowledge content, greater productivity and higher value added ([65]; Edquist [15]).

In Sweden, service industries[1] accounted for approximately 12% of the industrial energy consumption and 13% of the total industrial CO_2 emissions in the year 2008. In the same year, this sector accounted in Sweden for approximately 66% of the industrial employment, 52% of the industrial gross production and 64%

[1] These statistics not include transport activities and electricity, gas and water supply.

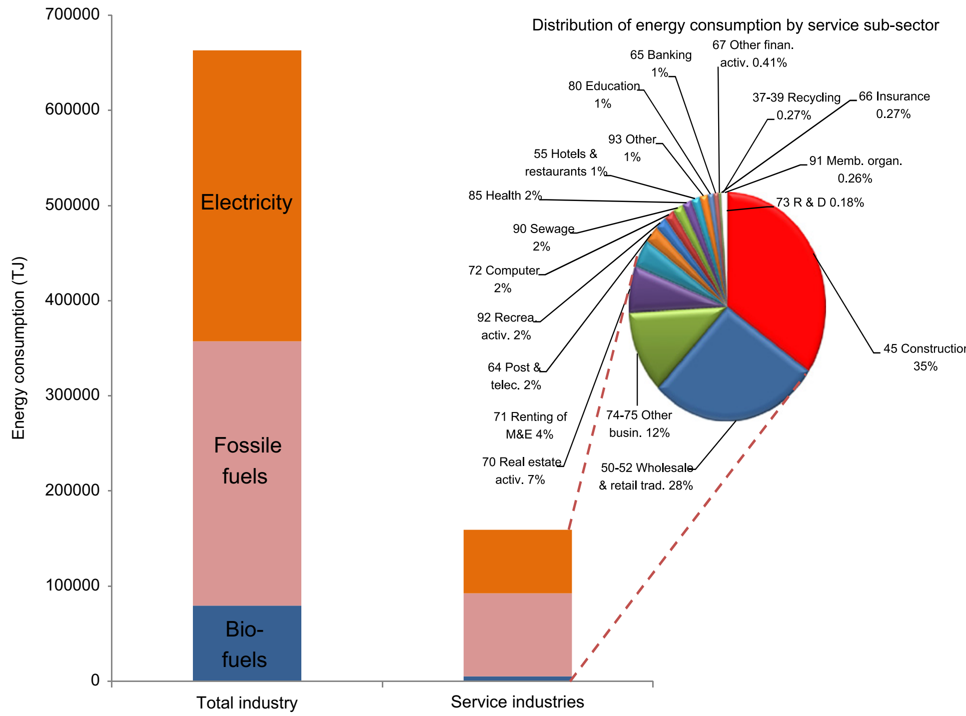

Fig. 1. Comparison of energy consumption by the Swedish service industries, 2008.
Source: SCB (Statistics Sweden).

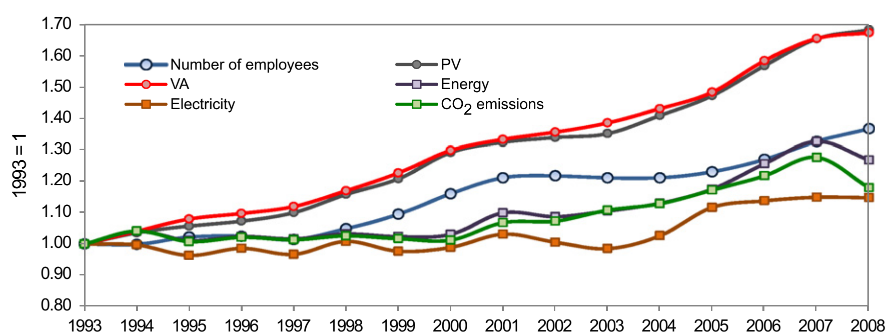

Fig. 2. Activity indicators for the Swedish service industries.
Source: SCB (Statistics Sweden).

of the industrial value added and consisted of 500,000 companies [61]. In terms of costs, energy is approximately 1.19% of the total production costs; additionally, the service sector contributes an average of 75% of the electricity tax and 44% of the fuel taxes paid by the total Swedish industrial sector [59,61]. Fig. 1 depicts energy consumption of the service industries compared to the total Swedish industries and its distribution by service sub-sector.

With the tertiarisation of the economy in Sweden, economic growth has increased more quickly in service industries, at an average of 3.5% per year from 1993 to 2008 [61]. Fig. 2 shows the trends in activity and energy indicators in the service industries in this period. Production value, value added and employment increased by 68%, 67% and 37%, respectively, while energy, electricity consumption and CO_2 emissions increased by 27%, 15% and 17%, respectively [61]. In absolute terms, service industries have driven the increase in total energy consumption for the whole Swedish industrial sector. In manufacturing industries, especially the energy-intensive sectors, strong reductions in energy intensity and CO_2 emission intensity have offset the effect of growth; therefore, the net increase on energy consumption by this sector has been insignificant[2] [50].

3. Methodology issues and data

In this section, we present an explanation of the methodology and data used to study energy use and CO_2 emissions in Swedish service industries. This analysis is divided in three stages: (i) energy use and CO_2 emissions are assed with traditional indicators (energy intensity and CO_2 emission intensity); (ii) data envelopment analysis is applied to determine relative efficiencies in the energy use, and two models are proposed; and (iii) Regression analysis is applied using panel data techniques to determine factors that could affect the trends in energy efficiency in Swedish services industries.

[2] The Swedish manufacturing industry decreased its energy consumption by 1.5%, whereas the service industry increased its energy consumption by 27% in the same period 1993–2008 [61].

3.1. Energy use and CO_2 emissions

First, it examines the traditional indicators of energy efficiency and CO_2 emissions by computing the energy intensities and CO_2 emission intensities (energy consumption or CO_2 emissions per unit of value added and energy consumption or CO_2 emissions per employee). Changes in energy and CO_2 emission intensities can be used as indicators of change in energy efficiency or results of CO_2 emissions [48,30,38].

3.2. Data envelopment analysis for measuring energy efficiency and CO_2 emissions performance

DEA is a nonparametric method for assessing the efficiency of n decision making units (DMUs) that consume various inputs to produce different outputs. This technique was proposed by [9]. The fundamental feature of DEA is that the technical efficiency score of each DMU depends on the performance of the sample of which it is a part. This means that DEA produces relative, rather than absolute, measures of technical efficiency for each DMU under consideration. DEA evaluates a DMU as technically efficient if it has the best ratio of any output to any input; this shows the significance of the outputs/inputs taken under consideration [23].

DEA considers that a service industry producing a vector of n outputs y from a vector of n inputs $x=(x_1, x_2,\ldots, x_n)$. Let the vector y_i represent the output package and the vector x_i represent the input package of the ith DMU, $i=1,\ldots,m$. Suppose that input–output data are observed for m DMUs. Then, the technology set can be completely characterised by the production possibility set $S=\{(x, y)$: *y can be produced from x*$\}$ based on a few regularity assumptions of feasibility for all observed input–output combinations[3], free disposability with respect to inputs and outputs[4], and convexity[5] . If, in addition, a constant return to scale is assumed, then this implies that all radial expansions, as well as (non-negative) contractions of the feasible input–output combinations, are also considered feasible. In this two DEA models are applied.

3.2.1. DEA model (1)

Following Mukherjee [43], this model measures the input-oriented technical efficiency that is defined as the ratio of the optimal (i.e., minimum) input package to the actual input package of a DMU for a given level of output, holding input proportions constant (technical efficiency). The CCR DEA model for measuring the input-oriented technical efficiency of a DMU with the input–output package (x_0, y_0) is represented as follows:

$$\theta^* = \min\theta \tag{A1}$$

subject to

$$\sum_{i=1}^{n} x_{ji}\lambda_i \le \theta_{xi0}(j = Capital, Labour, materials, endergy) \tag{A2}$$

$$\sum_{i=1}^{n} y_i\lambda_i \ge y_0(output) \tag{A3}$$

$$\lambda_i \ge 0,\ i = 1,2,\ldots,n \tag{A4}$$

where θ is the total imputs, n is the number of DMUs, x_{ji} is the amount of input j of DMUn, y_i is the amount of output of DMUn, λ_i is the non-negative multipliers that define the target operation $\times$ point as a; linear combination of the sample observations.

The objective of this model is to reduce all inputs to the largest extent possible by the same proportion to accommodate any potential complementarily between energy and other inputs. Moreover, the inequality (1c) ensures that the resultant output is no lower than what is actually being produced. An efficient DMU will have $\theta^*=1$, implying that no equi-proportionate reduction in inputs is possible, whereas an inefficient DMU will have $\theta^*<1$ In this model, each service industry requires energy and other inputs (labour, capital and materials) to produce desirable outputs.

3.2.2. DEA model (2)

A common feature of the first models is that energy consumption is an input within a production framework where energy and other non-energy inputs are used to produce good or desirable outputs. However, energy use also generates some undesirable outputs, e.g., CO_2 emissions, as by-products of producing desirable outputs. Model (2) evaluates energy efficiency performance within a joint production framework in which both desirable and undesirable outputs are considered simultaneously. Following Zhou and Ang [69] and Ramanathan [49], the model considers a production process in which desirable and undesirable outputs are jointly produced by energy input and non-energy inputs. Assume that x and y are, respectively, the vectors of energy and non-energy inputs and desirable and undesirable outputs. The model is as follows:

$$\phi^* = \max\phi \tag{B1}$$

subject to

$$\sum_{j=1}^{n} x_{mj}\lambda_j \le x_{m0}(m = capital, labour, materials, and\ endergy) \tag{B2}$$

$$\sum_{j=1}^{n} y_{pj}\lambda_j \le \phi x_{p0}(p = desirable\ output, and\ undesirable\ output) \tag{B3}$$

$$\lambda_j \ge 0,\ j = 1,2,\ldots,n \tag{B4}$$

$$\phi :\ = total\ ouputs$$

Note that in this model the inputs and outputs are not specified in the traditional sense of DEA models because CO_2 emissions are an undesirable output. The literature suggests several methods to treat undesirable outputs in the context of DEA; e.g., the undesirable output may be analysed as an input because it has the characteristic of an input (less of it is preferable), but the interpretation of results is difficult [57]. The undesirable output can be assigned a negative sign, but many DEA models are not invariant with respect to adding different signs between inputs and outputs [39]. Finally, the reciprocal value of the undesirable output may be used to incorporate the feature that more desirable outputs are preferred ([49,69]). In this model, when the score is equal to one, the service sector is efficient, whereas scores below one represent lower efficiencies. This indicates that a service industry with a score equal to one produces more output and less CO_2 emissions given the energy and non-energy inputs consumed by a relatively lower amount of energy input.

In order to determine whether the results from DEA models are an adequate approach for measuring energy efficiency and CO_2 emissions, we apply the Wilcoxon rank-sum test as a

[3] All observed input–output combinations are feasible.

[4] Free disposability means what if we can produce a certain output with a given combination of inputs, then with those inputs, we can always produce strictly less; e.g., we can produce the original amount we had before and then throw away the excess at no additional cost or without using any more inputs [56].

[5] Convexity implies that if there is a production activity y that produces a certain amount of output z using capital and labour in particular amounts and another activity w that produces the same quantity using different amounts of these inputs, then we can always produce z by mixing these activities and using y, a fraction λ of the time and w a fraction $(1-\lambda)$ of the time [56].

nonparametric alternative to evaluate whether differences between the two groups are significant. This test is applied to determine whether empirical distributions of DEA scores $\hat{F}(\hat{\hat{\varepsilon}}_j^{DEA})$ and traditional indicators of energy efficiency and CO_2 emissions $\hat{F}(\hat{\hat{\varepsilon}}_j^{TI})$ are different. The hypothesis of this test is that the distribution of *X*-measurement in the sample A (energy intensity and CO_2 emission intensity) is the same as in the sample B (DEA scores) containing η_A and η_B observations, respectively [12].

3.3. Determinants of energy efficiency applying econometric models

To investigate the factors that might explain differences in efficiency levels across Swedish service industries during the sample period, panel data techniques are used. The literature has demonstrated that OLS may be sufficient, and it does provide consistent estimates for second-stage regression from results obtained with DEA models [27,3].

The scores obtained from DEA models and energy intensity (EEM) are defined as dependent variables in several panel data models that included various possible determinants of energy efficiency. The scores of DEA are log-transformed due to the skewness of DEA scores and to improve normality. The model performed in this study is as follows:

$$\mathrm{EEM}_{i,t} = \alpha_0 + \alpha_1 ET_{i,t} + \alpha_2 ES_{i,t} + \varepsilon_{i,t} \tag{C1}$$

where $\mathrm{EEM}_{i,t}$ is the DEA score or energy intensity; $ET_{i,t}$ represents the energy taxes applied to Swedish service industry such as CO_2, fuel and electricity taxes in the period *t* for the service industry *i*; $ES_{i,t}$ is a vector that contains energy sources as electricity and fossil fuels with the aim to analyse the effects of fuel substitution in the period *t* for the service industry *i*. The hypothesis that drives the analysis implies that higher energy taxes and electricity consumption, generate higher energy efficiency, whereas higher fossil fuel consumption decreases energy efficiency and increases CO_2 emissions. The application of panel data techniques implies the following stages:

a. *Selection of panel data model.*
   To select the adequate panel model first, we apply the *F* test of the pooled OLS model against the fixed effects model [21]. In the case, that we reject the null hypothesis and select the fixed effects model. Next, we apply the Breusch and Pagan test of pooled OLS against the random effects model [4,2]. Finally, we employ the Hausman test of fixed effect against random effects [25].
b. *Assessment of the consistency and robustness of estimations.*
   To determine whether the estimation is consistent and robust, in each regression model we test for heteroscedasticity with the likelihood ratio (LR) test [44] and for serial autocorrelation using the Wooldridge test [21].
c. *Applications of regressions to correct problems in the estimations.*
   Maximum likelihood estimation (MLE) for random effects can be used to estimate a random effects model which allows corrections for autocorrelation and heteroscedasticity [35,6].

3.4. Dataset description

A dataset with 20 Swedish service industries is collected from Swedish statics offices and International Standard Industrial Classification (ISIC Rev. 3.1)[6]. This study excludes the following service industries: (40) electricity, gas, steam and hot water supply, (41) the collection, purification and distribution of water and (60–63) transport activities. In the application of the DEA models, four inputs are considered: capital, labour, materials and energy. The desirable output is represented as the production value of service production in each activity, deflated to 2005 euro values, while CO_2 emissions were the undesirable output, measured in metric tons of CO_2 emissions[7] .

The inputs for all 20 Swedish service industries (DMUs in DEA) are as follows: the capital input is measured as a stock by taking the value of gross fixed value; labour is measured by the total the expenditures in wages and salaries in euros by service activity; energy is the final energy consumption by service activity measured in Terajoules (TJ); and materials is measured by expenditure on materials. All monetary variables are deflated to 2005 euro values.

The data sources for the Swedish service industries were as follows: the systems of environmental and economic accounts of Statistics Sweden, Eurostat and database of the Organisation for Economic Co-operation and Development (OECD) in the industry and services module.

4. Results and discussion

In this section, results on energy use and CO_2 emissions derived from the methods in Section 3 are presented and discussed. First, traditional indicators for energy efficiency and CO_2 emissions are calculated. Second, energy efficiency and CO_2 emissions are analysed using DEA. Third, panel data analysis is applied to explain several determinants of trends in energy efficiency in Swedish service industries.

4.1. Energy intensity and CO_2 emission intensity

Fig. 3 shows the trends of energy intensity and CO_2 emission intensity. The average energy intensity for service industries over the total sample period was 0.786 TJ/million€ and 9.12 TJ/100 employees. CO_2 emission intensity had an average for this sector of 28.53 t/million€ and 3.95 t/employee. In both indicators, construction (45), machinery and equipment rental (71) and sewage and refuse (90) were of the highest intensity, while financial activities (65)–(67) and research and development activities (72) were of the lowest intensity. All service sectors displayed decreased energy intensity and CO_2 emission intensity per euro production value during the sample period, but increased energy intensity per employee. These results may indicate the importance of developing better habits and behaviour of employees to improve energy efficiency and decrease CO_2 emissions. This might be in line with the "efficiency paradox" in energy consumption that suggests that a substantial amount of investment in energy efficiency is not spontaneously undertaken by actors due to the presence of strong energy-inefficient habits. Therefore behaviour, habits and preferences are important determinates in the improvement of energy efficiency, especially in labour-intense sectors such as service industries. Changes in work habits related to energy use and efficiency require time and resources to guarantee their adoption and maintenance over time [42].

4.2. DEA results

Table 1 shows the results of the radial technical efficiency (θ) obtained from the first DEA model proposed. The value of θ

[6] The service industry in this study excludes (40) electricity, gas, steam and hot water supply, (41) the collection, purification and distribution of water and (60–63) transport activities.

[7] Total CO_2 emissions exclude bioenergy emissions.

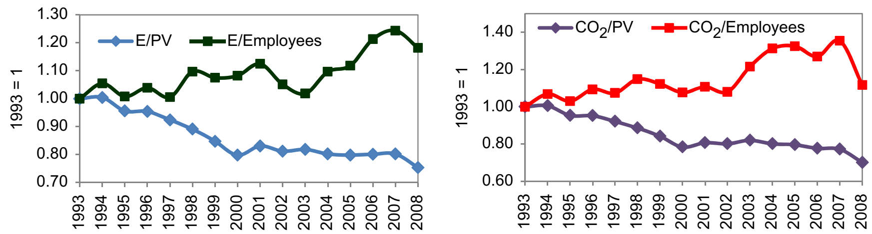

Fig. 3. Energy intensity and CO_2 emission intensity in Swedish service industries (energy or CO_2 emissions per production value or employee).
Source: SCB (Statistics Sweden).

Table 1
Radial technical efficiency (θ) and energy efficiency (ψ) from DEA model (1) and results (ϕ) from DEA model (2) for Swedish service industries.

Service sector	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Annual ave.
θ	0.654	0.536	0.720	0.762	0.669	0.775	0.729	0.735	0.737	0.750	0.691	0.776	0.746	0.802	0.682	0.751	0.719
ψ	0.627	0.559	0.714	0.837	0.598	0.705	0.665	0.543	0.646	0.558	0.403	0.676	0.636	0.705	0.614	0.734	0.639
ϕ	0.700	0.590	0.760	0.807	0.692	0.827	0.770	0.782	0.780	0.790	0.754	0.836	0.815	0.847	0.744	0.824	0.770

indicates the maximum proportional contraction of energy and non-energy inputs that could be realised without reducing output. The overall technical efficiency for Swedish service industries during the sample period was 0.719. Comparing across service industries (see Appendix A), efficiency varied across years and across the industries themselves. We observe that financial activities (65), (66), research and development (73) and other service activities (93) have higher technical efficiencies than the service industry in aggregate. Education (80), recreational, cultural and sporting activities (92) and sewage and refuse disposal (90) have lower technical efficiencies. The other service sectors have technical efficiencies close to that overall service industry.

The results of energy efficiency (ψ) obtained by slacks associated with the constraint for energy input in the first model are presented in Table 1 and Appendix A. The average energy efficiency in Swedish service industries was 0.639. Real estate activities (70), financial activities (65–66) and other service activities (93) have higher energy efficiencies on average than the service industry on aggregate, whereas construction (45), health and social work (85) and education have the lowest energy efficiencies according to this approach.

The results of DEA model (2) are shown in Table 1 and Appendix A. The average result of this model in service industries is 0.770. Real estate activities (70), financial activities (65–66), other service activities (93) and research and development activities are the sectors that produce more output with less CO_2 emissions. Education (80), recreational, cultural and sporting activities (92) and health and social work (85) are sectors with the lowest efficiencies with respect to production and CO_2 emissions.

The results of DEA analysis indicate that several service industries have increased technical efficiencies and energy efficiencies while decreasing CO_2 emissions. However, this sector has more potential and opportunities to improve energy efficiency and decrease CO_2 emissions. The Expert Group on Energy Efficiency [17] indicated that industrial energy efficiency has improved at a rate of 1% annually in the last decades. However, several studies and experience demonstrate that improvements could arise at double this rate over the medium or long run [14,66,16].

Finally, to determine whether the results from DEA models are adequate to measure energy efficiency, the Wilcoxon test is applied. The test suggests that the results of the DEA models for energy intensity and CO_2 emission intensity are from the same distribution. This result is in accordance with the null hypothesis, H_0. The null hypothesis in each case is that the median of the coefficients of correlation for one treatment is equal to the median of the coefficients of correlation for another treatment. Table 2 shows the results of the Wilcoxon tests, which demonstrates that the DEA models used in this study are an adequate approach to measure energy efficiency and CO_2 emissions.

Table 2
The compared efficiency scores from the Wilcoxon signed ranks test.

Pairs	Wilcoxon signed ranks test	
	Z	*P*-value
DEA ψ vs. EI (Energy consumption/production value)	−8.617	0.000
DEA ψ vs. EI (Energy consumption/employee)	−15.11	0.000
DEA ψ vs. CO_2I (CO_2 emissions/production value)	−15.11	0.000
DEA ψ vs. CO_2I (CO_2 emissions/employee)	13.82	0.000
DEA ϕ vs. EI (Energy consumption/production value)	−6.158	0.000
DEA ϕ vs. EI (Energy consumption/employee)	−15.11	0.000
DEA ϕ vs. CO_2I (CO_2 emissions/production value)	−15.11	0.000
DEA ϕ vs. CO_2I (CO_2 emissions/employee)	−12.59	0.000

Notes: EI: Energy intensity, CO_2I: CO_2 emission intensity.

4.3. *Analysis of determinants of energy efficiency in Swedish service industries*

To explain the observed variation and main factors that determine energy efficiency across service industries, panel data techniques are applied according to methods explained in Section 3.3. The results of the DEA models and energy intensity are the dependent variables in the various regression models.

Table 3 depicts the results of the econometric models for energy efficiency from DEA models (1) and (2) and energy intensity based on the production value and the number of employees. The four estimations show similar results. The specifications of the test to determine the adequate panel data model indicate that for all models a random effects model is appropriate. The estimation of residuals with random effects shows heteroscedasticity and serial correlation problems that must be corrected using MLE for random effects, which accounts for these problems. In general, the results illustrate that higher energy taxes and electricity consumption generate higher energy efficiency, while higher fossil fuel consumption decreases energy efficiency.

Table 3
Results of the econometric model for energy efficiency (EE-DEAψ and EE-DEAϕ) and energy intensity (EI).

Variables	Dependent variable							
	EE DEAψ		EE DEAϕ		EI (Energy/production value)		EI (Energy/employee)	
	Random effects	MLE	Random effects	MLE	Random effects	MLE	Random effects	MLE
Constant	−0.944**(0.412)	−0.935**(0.375)	−0.037(0.362)	−0.020(0.350)	−3.348***(0.539)	−3.348***(0.534)	−3.553***(0.444)	−3.572***(0.459)
Energy taxes	0.091(0.159)	0.092(0.159)	0.088***(0.028)	0.087***(0.028)	−0.080**(0.033)	−0.080**(0.033)	−0.137***(0.019)	−0.137***(0.019)
Fossil fuel consumption	−0.194(0.301)	−0.198(0.300)	−0.067*(0.051)	−0.069*(0.050)	0.475***(0.051)	0.475***(0.051)	0.834***(0.041)	0.836***(0.041)
Electricity consumption	0.032(0.055)	0.031(0.051)			−0.083*(0.051)	−0.083*(0.050)	−0.064*(0.038)	−0.064*(0.038)
Natural gas consumption			0.012(0.010)	0.012(0.010)				
***F*-test statistic**	$F(18, 263)=3.08$		$F(18, 282)=66.64$		$F(18, 282)=159.37$		$F(18, 282)=344.36$	
	0.000 Reject OLS		0.000 Reject OLS		0.000 Reject OLS		0.000 Reject OLS	
LM test	$\text{chibar}^2(01)=25.07$		$\text{chibar}^2(01)=1417.45$		$\text{chibar}^2(01)=1664.11$		$\text{chibar}^2(01)=^2030.42$	
Prob > chibar²	0.000 Reject OLS		0.000 Reject OLS		0.000 Reject OLS		0.000 Reject OLS	
Hausman test	$\text{chi}^2(5)=1.43$		$\text{chi}^2(5)=1.03$		$\text{chi}^2(6)=3.55$		$\text{chi}^2(5)=5.80$	
Prob > chi²	0.697 Reject *FE*		0.793 Reject *FE*		0.314 Reject *FE*		0.121 Reject *FE*	
Test for heteroscedasticity[a]	LR $\text{chi}^2(19)=249.08$		LR $\text{chi}^2(19)=^2942.94$		LR $\text{chi}^2(19)=3877.83$		LR $\text{chi}^2(19)=4973.49$	
Prob > chi²	0.000		0.000		0.000		0.000	
Wooldridge test for autocorrelation[b]	$F(1, 18)=0.010$		$F(1, 18)=0.009$		$F(1, 18)=263.69$		$F(1, 18)=55.99$	
Prob > *F*	0.921		0.927		0.000		0.000	
No. Obs	304	304	304	304	304	304	304	304

Notes: Figures in the parentheses are standard errors.

[a] If Prob > $\text{chibar}^2 < 0.05$, indicate heterocedasticity.

[b] If Prob > $F > 0.05$, indicate no serial correlation.

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.

Energy taxes have a positive effect on energy efficiency. In the service sector, these taxes include the energy tax and the CO_2 tax, which is levied on the consumption of light fuel oil. The Swedish energy and carbon taxation system is considered important and innovative because the taxes were indexed and linked to the consumer price index in Sweden. This design ensures a constant real value of the tax rates [59]. However, the impact and effects of these taxes have been limited in Swedish industry for three main reasons. First, the exemptions to the taxes on industry have resulted in a true taxation level of only 20% of the total energy and CO_2 taxes. For example, in 1993, the energy and CO_2 tax rate was around 25.2 €/1000 L for industry and total tax was around 160.1 €/1000 L; it increased to around 60 €/1000 L for industry and 365 €/1000 L for total tax between 2005 and 2008. Second, only a relatively small fraction of the energy supply to industry was fossil fuel-based when the taxes were applied in the 1990s. Third, for most industrial companies, especially service industries, energy costs are a relatively small fraction of total costs (< 3%) and have therefore a low priority [59,33,24,45]. These facts align with the result that energy taxes only have a significant coefficient in three models.

Fossil fuel, electricity and natural gas consumption are included to determine the role of fuel substitution in the improvements of energy efficiency. They are significant and have opposite signs, which indicate that a decrease in fossil fuel consumption and an increase in electricity and natural gas consumption have generated improvements in energy efficiency in Swedish service industries. Swedish electricity generation is not carbon-intensive and is based largely on nuclear and hydropower and on industrial and direct-heating cogeneration plants [63,64]. These facts demonstrate that it is possible to achieve energy efficiency and decrease CO_2 emissions through the use of high quality, clean fuels.

The results of these studies are important for designing adequate energy policies to increase energy efficiency and decrease CO_2 emissions in service industries. These policies are important because energy consumption grew most quickly in this sector and have driven the increase in total energy consumption for the whole Swedish industrial sector. The strategies for significant improvements in the service industry's energy efficiency must include access to information, energy management systems, improved decision-making processes, energy training for employees and the ability to measure and verify the achieved energy savings.

5. Conclusions

This paper analysed energy use and CO_2 emissions in the Swedish service industries during the period of 1993–2007 using several empirical approaches, including intensity indicators, DEA and panel data models. The tests used in the different techniques applied in this study demonstrate that the methods are adequate to generate consistent, robust and reliable estimates in the analysis of energy efficiency from traditional indicators and DEA. Energy efficiency and CO_2 emission intensity varied across years and across service industries.

The results of the DEA analysis indicate that several service industries have increased technical efficiency and energy efficiency while decreasing CO_2 emissions. However, this sector has more potential and opportunity to improve energy efficiency and decrease CO_2 emissions. Regression analysis using panel data techniques show that higher energy taxes and electricity consumption generate higher energy efficiency, while higher fossil fuel consumption leads to lower energy efficiency.

Table A1
Radial technical efficiency (θ) and energy efficiency (ψ) from DEA model (1) for Swedish service industries.

Service sector	1993		1994		1995		1996		1997		1998		1999		2000	
	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ
37–39 R&JT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.86
45 Cons.	1.00	1.00	0.48	0.89	1.00	1.00	1.00	1.00	0.99	0.95	1.00	1.00	1.00	1.00	0.88	0.80
50–52 W&RT	1.00	1.00	0.53	0.32	0.75	0.77	1.00	1.00	0.87	0.66	1.00	1.00	1.00	1.00	0.90	0.48
55H&R	0.73	0.02	0.51	0.17	0.62	0.54	0.82	0.99	0.76	0.33	1.00	1.00	1.00	0.10	0.76	0.10
64 P&T	0.63	0.32	0.46	0.47	0.52	0.28	0.62	0.87	0.57	0.51	0.67	0.52	0.70	0.97	0.56	0.10
65 Bank	1.00	1.00	0.93	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
66 I&PF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.90	1.00	1.00	1.00	1.00	0.90	0.89
67 OFA	0.51	0.26	0.51	0.25	0.57	0.57	0.67	0.66	0.63	0.33	0.65	0.45	0.72	0.40	0.70	0.37
70 REA	1.00	1.00	0.55	0.71	0.70	0.70	1.00	1.00	0.89	0.36	1.00	1.00	1.00	1.00	0.80	0.56
71 RM&E	0.48	0.72	0.46	0.53	0.51	0.91	0.66	0.86	0.53	0.58	0.58	0.30	0.62	0.20	0.53	0.18
72 Comp.	0.50	0.96	0.50	0.35	0.86	0.86	0.84	0.83	0.65	0.46	0.72	0.13	0.75	0.43	0.74	0.92
73 R&D	1.00	1.00	0.96	0.10	1.00	1.00	0.97	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
74–75 OBA	0.74	0.58	0.40	0.35	1.00	1.00	1.00	1.00	0.76	0.58	1.00	1.00	0.88	0.20	1.00	1.00
80 Educ.	0.10	0.24	0.10	0.15	0.21	0.48	0.16	0.77	0.10	0.10	0.13	0.48	0.14	0.10	0.24	0.84
85H&SW	0.24	0.40	0.24	0.78	0.59	0.13	0.47	0.22	0.31	0.99	0.39	0.37	0.28	0.83	0.66	0.22
90 S&RD	0.39	0.64	0.38	0.55	0.47	0.46	0.45	0.88	0.37	0.26	0.41	0.75	0.41	0.99	0.54	0.19
91 MO	0.22	0.51	0.27	0.75	0.50	0.40	0.42	0.42	0.35	0.10	0.34	0.10	0.24	0.56	0.28	0.47
92 RC&SA	0.29	0.23	0.31	0.59	0.56	0.56	0.50	0.49	0.37	0.64	0.83	0.28	0.41	0.55	0.61	0.16
93 OSA	0.62	0.10	0.61	0.71	0.90	0.90	0.90	0.90	0.67	0.67	1.00	1.00	0.72	0.30	0.94	0.26

Service sector	2001		2002		2003		2004		2005		2006		2007		2008		Ave.	
	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ	θ	ψ
37–39 R&JT	1.00	1.00	0.89	0.63	0.84	0.10	1.00	1.00	1.00	1.00	1.00	1.00	0.78	0.80	0.61	0.49	0.94	0.86
45 Cons.	1.00	1.00	0.81	0.14	0.96	0.95	1.00	1.00	0.95	0.17	1.00	1.00	1.00	1.00	0.78	0.53	0.93	0.84
50–52 W&RT	1.00	1.00	0.92	0.74	0.84	0.41	1.00	1.00	0.94	0.95	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.83
55H&R	1.00	1.00	0.67	0.24	1.00	1.00	1.00	1.00	0.87	0.30	0.91	0.70	0.96	0.65	0.89	0.29	0.84	0.52
64 P&T	0.65	0.42	0.60	0.35	0.53	0.10	0.89	0.50	0.57	0.98	0.70	0.51	0.92	0.21	0.93	0.64	0.66	0.48
65 Bank	1.00	1.00	1.00	1.00	0.92	0.13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.94
66 I&PF	0.92	0.32	1.00	1.00	0.81	0.45	0.86	0.65	0.92	0.92	0.90	0.10	0.78	0.55	1.00	1.00	0.94	0.79
67 OFA	0.80	0.73	0.81	0.11	0.71	0.46	0.71	0.91	0.71	0.76	0.74	0.10	0.48	0.93	0.37	0.95	0.64	0.51
70 REA	0.85	0.10	1.00	1.00	0.72	0.51	1.00	1.00	0.72	0.10	1.00	1.00	0.61	0.54	1.00	1.00	0.87	0.72
71 RM&E	0.79	0.44	0.85	0.52	0.78	0.10	0.83	0.10	0.78	0.75	0.87	0.27	0.27	0.10	0.34	0.50	0.62	0.43
72 Comp.	0.78	0.91	0.84	0.10	0.78	0.34	0.88	0.56	0.85	0.55	1.00	1.00	0.88	0.94	1.00	1.00	0.79	0.64
73 R&D	0.76	0.22	1.00	1.00	0.73	0.40	1.00	0.22	0.84	0.51	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.77
74–75 OBA	0.82	0.69	1.00	1.00	0.85	0.25	0.95	0.84	0.97	0.74	1.00	1.00	0.81	0.50	1.00	1.00	0.89	0.73
80 Educ.	0.11	0.30	0.12	0.33	0.13	0.17	0.14	0.79	0.21	0.24	0.25	0.61	0.19	0.10	0.27	0.21	0.16	0.36
85H&SW	0.27	0.25	0.42	0.20	0.32	0.31	0.33	0.47	0.52	0.92	0.54	0.31	0.38	0.14	0.51	0.29	0.41	0.43
90 S&RD	0.60	0.49	0.63	0.47	0.59	0.73	0.57	0.36	0.60	0.63	0.61	0.74	0.38	0.63	0.36	0.14	0.48	0.56
91 MO	0.20	0.81	0.22	0.43	0.19	0.23	0.18	0.10	0.19	0.14	0.18	0.22	0.18	0.20	0.21	0.88	0.25	0.39
92 RC&SA	0.44	0.66	0.47	0.43	0.42	0.26	0.42	0.89	0.53	0.46	0.54	0.95	0.39	0.70	1.00	1.00	0.51	0.55
93 OSA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.54	1.00	1.00	1.00	1.00	0.95	0.79	1.00	1.00	0.84	0.76

Note: R&JT: 37–39 Recycling and Job training; Cons.: 45 Construction; W&RT: 50–52 Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods; H&R: 55 Hotels and restaurants; P&T: 64 Post and telecommunications; Bank: 65 Banking; I&PF: 66 Insurance and pension funding; OFA: 67 Other financial activities; REA: 70 Real estate activities; RM&E: 71: Renting of machinery and equipment; Comp.: 72 Computer and related activities; R&D: 73 Research and development; OBA: 74–75: Other business activities and public administration; Educ.: 80 Education; H&SW: 85 Health and social work; S&RD: 90 Sewage and refuse disposal; MO: 91 Membership organizations; RC&SA: 92 Recreational, cultural and sporting activities; OSA: 93 Other service activities.

Table A2
Results from DEA model (2) for Swedish service industries.

Service sector	1993 ϕ	1994 ϕ	1995 ϕ	1996 ϕ	1997 ϕ	1998 ϕ	1999 ϕ	2000 ϕ	2001 ϕ	2002 ϕ	2003 ϕ	2004 ϕ	2005 ϕ	2006 ϕ	2007 ϕ	2008 ϕ	Aver. ϕ
37–39 R&JT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	1.00	0.89	0.88	1.00	1.00	1.00	0.89	1.00	0.97
45 Cons.	1.00	0.48	1.00	1.00	0.99	1.00	1.00	0.88	1.00	0.81	0.96	1.00	0.95	1.00	1.00	0.78	0.93
50–52 W&RT	1.00	0.53	0.75	1.00	0.87	1.00	1.00	0.90	1.00	0.92	0.84	1.00	0.94	1.00	1.00	1.00	0.92
55H&R	0.73	0.51	0.62	0.82	0.76	1.00	1.00	0.76	1.00	0.67	1.00	1.00	0.87	0.91	0.97	0.89	0.84
64 P&T	0.63	0.46	0.52	0.62	0.57	0.67	0.70	0.56	0.65	0.60	0.53	0.89	0.57	0.70	0.92	0.93	0.66
65 Bank	1.00	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	1.00	1.00	1.00	1.00	1.00	0.99
66 I&PF	1.00	1.00	1.00	1.00	0.90	1.00	1.00	0.90	0.92	1.00	0.84	0.87	0.94	0.90	0.78	1.00	0.94
67 OFA	1.00	0.99	0.73	1.00	0.84	1.00	1.00	0.94	1.00	1.00	0.94	1.00	1.00	1.00	1.00	0.73	0.95
70 REA	1.00	0.55	0.70	1.00	0.89	1.00	1.00	0.80	0.85	1.00	0.72	1.00	0.72	1.00	0.61	1.00	0.86
71 RM&E	0.48	0.46	0.51	0.66	0.53	0.58	0.62	0.53	0.79	0.85	0.78	0.83	0.78	0.87	0.27	0.34	0.62
72 Comp.	0.50	0.50	0.88	0.85	0.65	0.72	0.75	0.74	0.78	0.84	0.78	0.88	0.85	1.00	0.88	1.00	0.79
73 R&D	1.00	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
74–75 OBA	0.74	0.40	1.00	1.00	0.76	1.00	0.88	1.00	0.82	1.00	0.85	0.95	0.97	1.00	0.81	1.00	0.89
80 Educ.	0.11	0.10	0.26	0.20	0.10	0.16	0.14	0.28	0.11	0.14	0.13	0.15	0.23	0.28	0.19	0.29	0.17
85H&SW	0.24	0.24	0.63	0.50	0.31	0.39	0.28	0.68	0.27	0.42	0.32	0.33	0.53	0.54	0.38	0.51	0.41
90 S&RD	0.39	0.38	0.47	0.45	0.37	0.41	0.41	0.54	0.60	0.63	0.59	0.57	0.60	0.61	0.38	0.36	0.48
91 MO	0.58	0.81	0.86	0.81	0.59	0.77	0.73	0.86	0.58	0.77	0.83	1.00	1.00	0.74	0.70	0.84	0.78
92 RC&SA	0.29	0.31	0.60	0.52	0.37	1.00	0.41	0.63	0.44	0.47	0.42	0.42	0.53	0.54	0.39	1.00	0.52
93 OSA	0.62	0.61	0.90	0.90	0.67	1.00	0.72	0.94	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	0.89

Note: R&JT: 37–39 Recycling and Job training; Cons.: 45 Construction; W&RT: 50–52 Wholesale and retail trade; repair of motor vehicles. motorcycles and personal and household goods; H&R: 55 Hotels and restaurants; P&T: 64 Post and telecommunications; Bank: 65 Banking; I&PF: 66 Insurance and pension funding; OFA: 67 Other financial activities; REA: 70 Real estate activities; RM&E: 71: Renting of machinery and equipment; Comp.: 72 Computer and related activities; R&D: 73 Research and development; OBA: 74–75: Other business activities and public administration; Educ.: 80 Education; H&SW: 85 Health and social work; S&RD: 90 Sewage and refuse disposal; MO: 91 Membership organizations; RC&SA: 92 Recreational. cultural and sporting activities; OSA: 93 Other service activities.

The results of these studies are important for better understanding the trends behind present industrial development, and for designing adequate energy policies to increase energy efficiency and reduce CO_2 emissions in service industries. Energy consumption has grown quickly in this sector and has driven the increase in total energy consumption for the whole Swedish industrial sector. The strategies for significant improvements in the service industry's energy efficiency must include access to information, energy management systems, improved decision-making processes, energy training for employees and appropriate methods to measure and verify the achieved energy savings. Further research is necessary for better understanding the barriers to adoption of energy efficient technologies, good practices and energy management systems in the service sector. Promoting energy efficiency improvements in the service sector is key to avoiding an inefficient growth path in a sector that is increasingly important for the country's welfare.

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Appendix A

See Tables A1 and A2.

References

[1] Azadeh A, Amalnick M, Ghaderi S, Asadzadeh M. An integrated DEA PCA numerical taxonomy approach for energy efficiency assessment and consumption optimization in energy intensive manufacturing sectors. Energy Policy 2007;35:3792–806.
[2] Baltagi B, Li Q. A Lagrange multiplier test for the error components model with incomplete panels. Econometric Reviews 1990;9:103–7.
[3] Banker T, Natarajan R. Evaluating contextual variables affecting productivity using data envelopment analysis. Operations Research 2008;56:48–58.
[4] Breusch T, Pagan R. The Lagrange multiplier test and its applications to model specification in econometrics. Review of Economic Studies 1980;47:239–53.
[5] Boyd G, Pang J. Estimating the linkage between energy efficiency and productivity. Energy Policy 2000;28:289–96.
[6] Calzolari G, Magazzini L. Autocorrelation and masked heterogeneity in panel data models estimated by maximum likelihood. Empirical Economics 2011, http://dx.doi.org/10.1007/s00181-011-0487-7.
[8] Central Intelligence Agency (CIA), 2011. The World Factbook. 〈https://www.cia.gov/library/publications/the-world-factbook/index.html〉.
[9] Charnes A, Cooper W, Rhodes E. Measuring the efficiency of decision- making units. European Journal of Operational Research 1979;3:429–44.
[11] Collard F, Feve P, Portier F. Electricity consumption and ICT in the French service sector. Energy Economics 2005;27:541–50.
[12] Cooper W, Seiford L, Tone K. Data Envelopment Analysis. A Comprehensive Text with Models, Applications, References and DEA-Solver Software. Second editionSpringer; 2007.
[13] Drucker P. Managing in the Next Society. New York: St. Martin Press; 2002.
[14] Ecofys, 2001. Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Top-down Analysis of Greenhouse Gas Emission Reduction Possibilities in the EU. Ecofys Energy and Environment, AEA Technology Environment and National Technical University of Athens. 〈http://ec.europa.eu/environment/enveco/climate_change/pdf/top_down_analysis.pdf〉.
[15] Edquist H. Intangible investment and the Swedish manufacturing and service sector paradox—what can Europe learn? IFN Working Paper no. 863. Research Institute of Industrial Economics, http://snee.org/filer/papers/627.pdf.
[16] European Commission (EC), 2006: Action Plan for Energy Efficiency: Realising the Potential. Brussels, Belgium. 〈http://ec.europa.eu/energy/action_plan_energy_efficiency/doc/com_2006_0545_en.pdf〉.
[17] Expert Group on Energy Efficiency. Realizing the Potential of Energy Efficiency: Targets, Policies, and Measures for G8 Countries. Washington, DC: United Nations Foundation; 2007 72 pp.
[18] Färe R, Grosskopf S, Lindgren B, Roos P. Productivity developments in Swedish hospitals: a malmquist output index approach. In: Charnes A, et al., editors. Data Envelopment Analysis: Theory, Methodology and Application, 253 ± 272. Boston, MA: Kluwer; 1995.
[19] Färe R, Grosskopf S, Forsund F, Hayes K, Heshmati A. Measurement of productivity and quality in non-marketable services with application to schools. Quality Assurance in Education 2006;14:21–36.
[21] Greene, W., 2011. Econometric Analysis. Pearson Education; Global ed. of 7th revised ed. Edition.
[22] Gowdy J, Miller J. Energy use in the U.S. service sector: an input-output analysis. Energy 1987;12:55–562.
[23] Halkos G., Tzeremes, N., 2005. A DEA Approach to Regional Development. MPRA Paper No. 3992. 〈http://mpra.ub.uni-muenchen.de/3992/〉.
[24] Harrison G., Kriström B., 1997. Carbon Taxes in Sweden. Final Report. 〈http://www-sekon.slu.se/~bkr/Carbon.pdf〉.
[25] Hausman J. Specification tests in econometrics. Econometrica 1978;46:1251–71.
[26] Hjalmarsson L, Veiderpass A. Productivity in Swedish electricity retail distribution. The Scandinavian Journal of Economics 1992;94:193–205.

[27] Hoff A. Second stage DEA: comparison of approaches for modelling the DEA score. European Journal of Operational Research 2007;181:425–35.
[28] Hu JL, Kao CH. Efficient energy-saving targets for APEC economies. Energy Policy 2007;35:373–82.
[30] International Energy Agency (IEA), 2007. Tracking Industrial Energy Efficiency and CO_2 Emissions. 〈http://www.iea.org/textbase/nppdf/free/2007/tracking_emissions.pdf〉.
[31] International Energy Agency (IEA), 2008. Worldwide Trends in Energy Use and Efficiency. Key Insights from IEA Indicator Analysis. In support of the G8 Plan of Action. 〈http://www.iea.org/papers/2008/indicators_2008.pdf〉.
[32] International Energy Agency (IEA), 2009. IEA Scoreboard 2009: 35 Key Energy Trends over 35 Years. 〈http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=2141〉.
[33] Johansson B., 2001. Economic Instruments in Practice 1: Carbon Tax in Sweden. Report Swedish Environmental Protection Agency. 〈http://www.oecd.org/dataoecd/25/0/2108273.pdf〉.
[34] Johansson H. 2005. Technical, Allocative, and Economic Efficiency in Swedish Dairy Farms: The Data Envelopment Analysis Versus the Stochastic Frontier Approach. European Association of Agricultural Economists. International Congress, Copenhagen, Denmark. 〈http://ageconsearch.umn.edu/handle/24478〉.
[35] Karlsson S, Skoglund J. Maximum-likelihood based inference in the two-way random effects model with serially correlated time effects. Empirical Economics 2004;29:79–88.
[36] Karmarkar U. Will you survive the services revolution? Harvard Business Review 2004;82:101–7.
[37] Krackeler T, Schipper L, Sezgen O. Carbon dioxide emissions in OECD service sectors: the critical role of electricity use. Energy Policy 1998;26:1137–52.
[38] Lapillonne B, Sebi C, Pollier K. 2011. Energy Efficiency Trends in EU Services. 〈www.odyssee-indicators.org/reports/services/services_eu27.pdf〉.
[39] Lowell J, Pastor T. Units invariant and translation invariant DEA models. Operations Research Letters 1995;18:147–51.
[41] Mairet N, Decellas F. Determinants of energy demand in the French service sector: a decomposition analysis. Energy Policy 2009;37:2734–44.
[42] Marechal K, Lazaric N. 2007. Changing Habits and Routines in Energy Consumption: How to Account for Both Individual and Structural Influences While Integrating the Motivational Dimension. 〈www.dime-eu.org/files/〉.
[43] Mukherjee K. Energy use efficiency in the Indian manufacturing sector: an interstate analysis. Energy Policy 2008;36:662–72.
[44] Nair A, Sarkar A, Ramanathan A, Subramanyam A. Anomalies in CAPM: a panel data analysis under Indian conditions. International Research Journal of Finance and Economics 2009;33:192–206.
[45] Organisation for Economic Co-operation and Development (OECD), 2001. Environmentally Related Taxes in OECD Countries. Issues and Strategies. 〈http://www.peblds.org/files/Publications/OECD/OECD_Environmentally_Related_Taxes.pdf〉.
[46] Oggioni G, Riccardi R, Toninelli R. Eco-efficiency of the world cement industry: a data envelopment analysis. Energy Policy 39 2011:2842–54.
[47] Pardo MCI. Energy efficiency development in the German and Colombian energy intensive sectors: a non-parametric analysis. WIT Transactions on Ecology and the Environment 2009;121:499–511.
[48] Phylipsen G, Blok K, Worrell E. Handbook on International Comparisons of Energy Efficiency in the Manufacturing Industry. Department of Science, Technology and Society, Utrecht University; 1998.
[49] Ramanathan R. A multi-factor efficiency perspective to the relationships among world GDP, energy consumption and carbon dioxide emissions. Technological Forecasting & Social Change 2006;73:483–94.
[50] Ramirez C, Patel M, Blok K. The non-energy intensive manufacturing sector: an energy analysis relating to the Netherlands. Energy 2005;30:749–67.
[51] Salas O. 1998. Technical Efficiency During Deregulation of the Urban Bus System in Sweden. Working Papers in Economics No 4. School of Economics and Commercial Law Göteborg University.
[52] Schipper L, Meyers S, Ketoff A. Energy use in the service sector. an international perspective. Energy Policy 1986;14:201–18.
[53] Schleich J. Barriers to energy efficiency: a comparison across the German commercial and services sector. Ecological Economics 2009;68:2150–9.
[55] Schlomann B, Kleeberger H, Herzog T. Energy Consumption of the Tertiary Sector (Trade, Commerce and Services) for the Years 2004 to 2006. Project Number 45/05. Fraunhofer Institute for Systems and Innovation Research (ISI), Lehrstuhl für Energiewirtschaft und Anwendungstechnik (IfE) and GfK Marketing Services GmbH & Co. KG; 2009.
[56] Schotter A. Microeconomics. A modern approach. USA: South Western Cengage Learning; 2009.
[57] Schuschny A. The DEA method and its application to energy sector and CO_2 emissions in Latin American and the Caribbean. CEPAL, Statistic and Prospective Studies 2007 In Spanish.
[58] Scrase I. White Collar CO_2: Energy Consumption in the Service Sector. London: The Association for the Conservation of Energy; 2000 〈http://www.ukace.org/〉.
[59] Speck S. The design of carbon and broad-based energy taxes in European countries. In the reality of Carbon taxes. In the 21st Century. A Joint Project of the Environmental Tax Policy Institute and the Vermont Journal of Environmental Law Vermont Law School 2008.
[61] Statistics Sweden. 2010, National Accounts, Detailed Yearly Estimates, 1950–2007, 〈www.scb.se〉.
[62] Stern R. 2005. The Place of Services in the World Economy. Research Seminar in International Economics. Discussion Paper No. 530. 〈http://www.spp.umich.edu/rsie/workingpapers/wp.html〉.
[63] Sweden energy. 2011. The Electricity Year 2010. 〈http://www.svenskenergi.se/upload/Statistik/Elåret/ENG_Sv%20Energi_elåret2010.pdf〉.
[64] Swedish Institute. 2011. Energy: generating power for a Sustainable Future. 〈http://www.sweden.se/upload/Sweden_se/english/factsheets/SI/SI_FS3_Energy/FS3-Energy-low-resolution.pdf〉.
[65] The Swedish ministry of industry, employment and communications. 2004. Innovative Sweden. A Strategy for Growth through Renewal. Ds 2004:36. 〈www.sweden.gov.se/content/1/c6/03/25/51/29e722a9.pdf〉.
[66] WEC. Energy Efficiency: A Worldwide Review. London: World Energy Council; 2004.
[69] Zhou P, Ang W. Linear programming models for measuring economy-wide energy efficiency performance. Energy Policy 2008;36:2911–6.
[70] Pardo MCI. Energy efficiency development in German and Colombian non-energy-intensive sectors: a non-parametric analysis. Energy Efficiency 2011;4:115–31.